The Causal Relationship between Moist Diabatic Circulation and Cloud Rapid Adjustment to Increasing CO_2

Tra Dinh

THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

Stephan Fueglistaler

PRINCETON UNIVERSITY

Following an increase in CO_2, the perturbation in the atmosphere's radiative budget drives rapid adjustment (Gregory et al 2004).

Adjustment takes place rapidly within ~ 10 days in the troposphere (independently of slow surface warming).

Decrease in radiative cooling in the troposphere drives adjustment, including:

- weakened hydrologic cycle; sensible and latent heat fluxes decrease,
- decrease of clouds in the free troposphere (Kamae et al 2015).

Decrease of clouds during rapid adjustment contributes $\sim 1\,\mathrm{W\,m^{-2}}$ per $4 \times \mathrm{CO_2}$ to effective forcing (Zelinka et al 2013).

Proposed mechanism for cloud adjustment

CO_2 increases (fixed surface temperature)

$\Downarrow$

Radiative cooling decreases

$\Downarrow$

?

$\Downarrow$

?

$\Downarrow$

Cloud water decreases

Proposed mechanism for cloud adjustment

CO_2 increases (fixed surface temperature)

$\Downarrow$

Radiative cooling decreases

$\Downarrow$

Circulation weakens

$\Downarrow$

Condensate production decreases

$\Downarrow$

Cloud water decreases

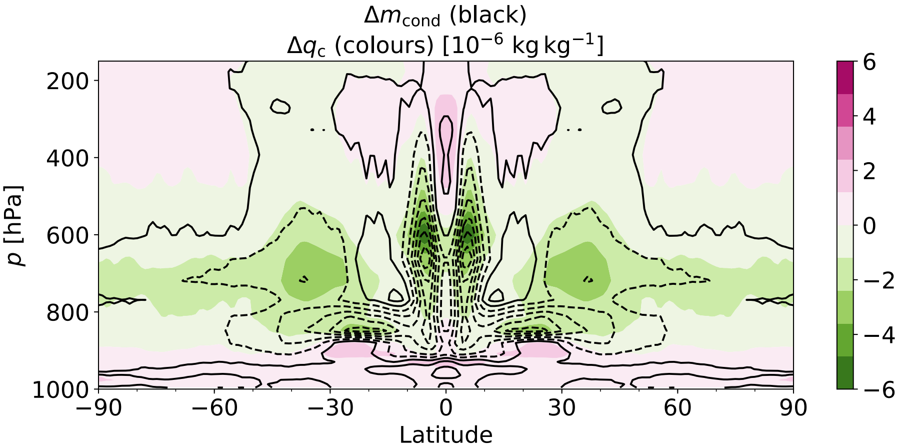
GCM simulations

Mechanism is tested in aquaplanet simulations carried out using HiRAM (GFDL).

We also check against CMIP5 AMIP experiments (not shown in this talk).

The rate of condensate production m_{cond} ($\text{kg}\,\text{kg}^{-1}\,\text{s}^{-1}$) is the rate at which water vapour is converted to condensates in the atmosphere making clouds.

First we compare change of m_{cond} during rapid adjustment with change in cloud water (ice and liquid) mixing ratio q_{c}.



Changes in condensate production Δm_{cond} and cloud mixing ratio Δq_{c} in aquaplanet HiRAM simulations.

The decrease in condensate production Δm_{cond} explains the decrease in cloud water Δq_{c}.

Changes during rapid adjustment of subsequent processes of cloud evolution have only small impacts on q_{c}.

We now link Δm_{cond} to the weakening of the circulation and to ΔQ_{rad}.

In the free troposphere, on the global average, ascending motion driven by latent heating is balanced by subsidence by radiative cooling:

$$[\omega_{\mathrm{lat}}] = -[\omega_{\mathrm{rad}}],$$

where

$$\omega_{\mathrm{rad}} \equiv -\frac{Q_{\mathrm{rad}}}{\sigma}$$

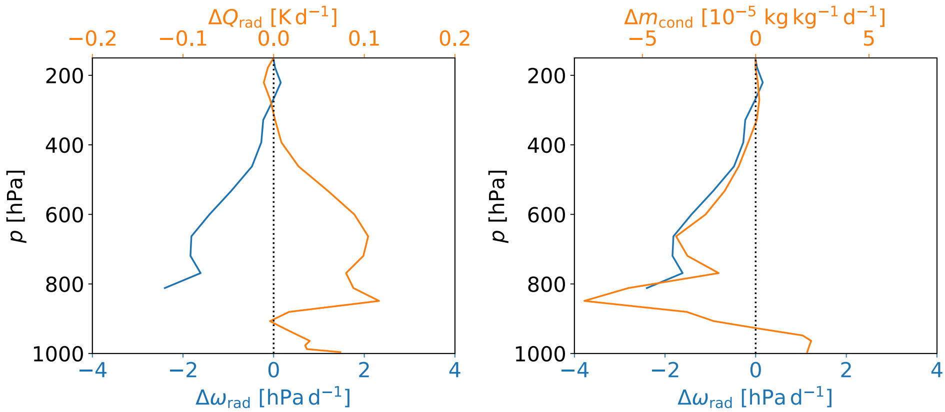
quantifies the strength of the diabatic circulation, where σ is the static stability.

The rate of condensate production is estimated by

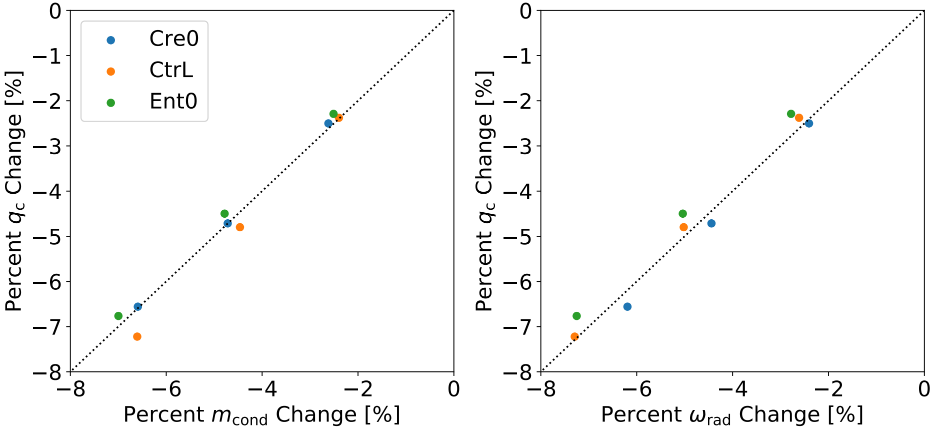
$$[m_{\mathrm{cond}}] \sim -[\omega_{\mathrm{lat}}] \left[\frac{\mathrm{d}q_{\mathrm{sat}}}{\mathrm{d}p}\right] = [\omega_{\mathrm{rad}}] \left[\frac{\mathrm{d}q_{\mathrm{sat}}}{\mathrm{d}p}\right]$$

for the free troposphere only (above $\sim 800\,\mathrm{hPa}$).

$[\cdot]$ indicates global average.



ΔQ_{rad} drives $\Delta\omega_{\mathrm{rad}}$, which leads to Δm_{cond}.



Three model configurations (control, cloud radiative effect off, boundary layer entrainment off) with 2×, 4× and 8×CO_2.

Proposed mechanism for cloud adjustment

CO_2 increases (fixed surface temperature)

$\Downarrow$

Radiative cooling decreases

$\Downarrow$

Circulation weakens

$\Downarrow$

Condensate production decreases

$\Downarrow$

Cloud water decreases

Proposed mechanism for cloud adjustment

Decrease of cloud water during rapid adjustment is a result of the weakening of the moist diabatic circulation (Dinh & Fueglistaler, 2019, under review).

In paper we also discuss:

- Change in cloud fraction (not identical to change in cloud water)
- Change in boundary layer clouds
- Role of RH change